NPOI

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MISSILES AND SPACE SECTOR
ADVANCED TECHNOLOGY CENTER

NPOI Line of Sight Control Experiments

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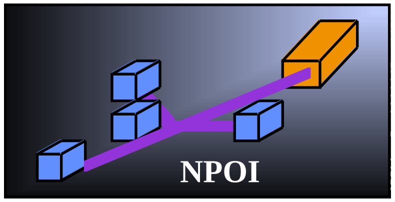

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Key Drivers for Future Imaging Systems

Earth Resources

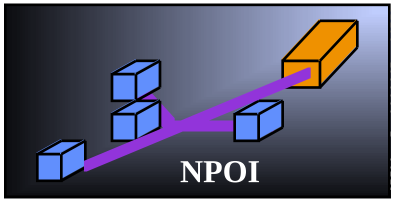
- access time
- revisit time
- area coverage
- cost

Astronomy & Astrophysics

- resolution
- faint object detection
- background suppression
- cost

Next Generation Imaging System

- large effective aperture
- “deployed” on orbit
- sparse aperture (if possible)



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Next Generation Space based Imaging Systems

Common Technologies

- telescope phasing
- LOS control
- wavefront tilt control
- image stabilization
- lightweight structures
- lightweight optics
- fast steering mirrors
- deployment mechanisms
  - > latches
  - > hinges
- isolation / damping
- focal planes
- active control loops
- control loop capture
- precision alignment

Unique Technologies

Earth Resources
- scene independent phasing sensor
- pupil mapping control

SIM
- long baseline precision metrology
- interference fringe tracking

NGST
- low temperature components
- phasing sensor for long integration times

Planet Finder
- long baseline precision metrology
- nulling interferometer

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MultiAp Risk Reduction Experiments Objectives

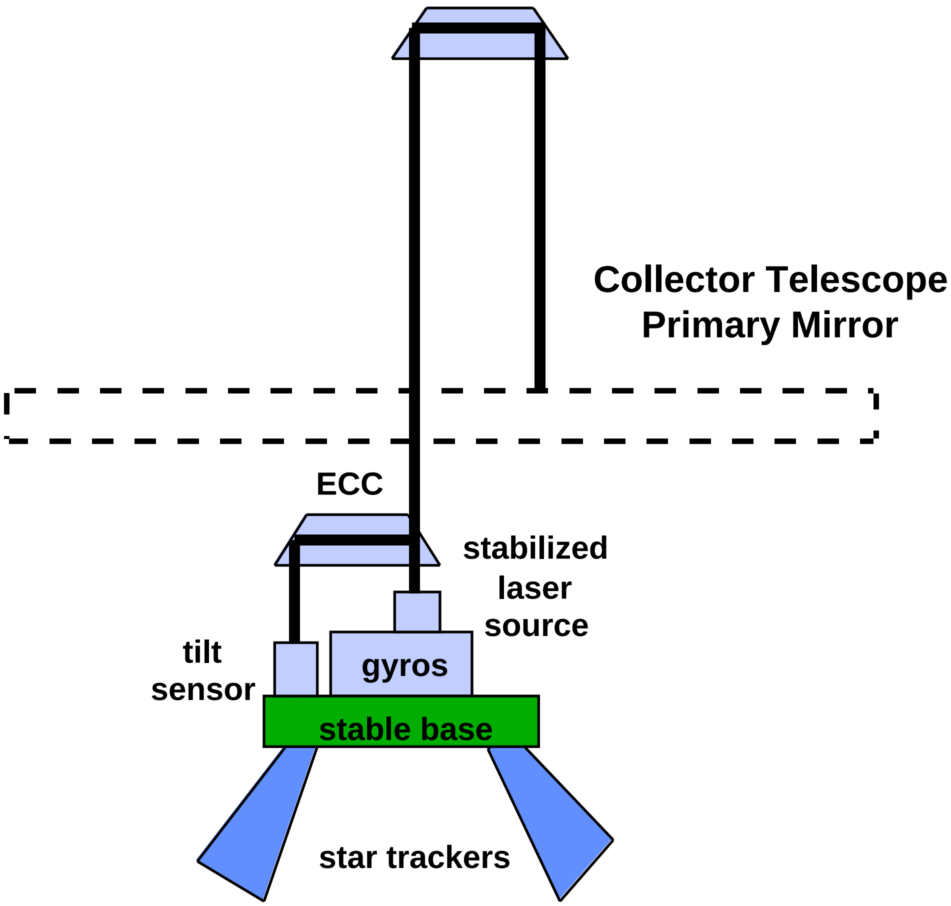
- **Demonstrate performance of wavefront tilt control loop**
  - **wavefront aberrations due to relative tilt errors between collector telescope / optical delay line paths at the beam combiner entrance pupil**
- **Demonstrate image stabilization control loop**
  - **dynamic, global line of sight errors resulting in image motion at the primary focal plane**
- **Demonstrate active line of sight pointing**
  - **absolute line of sight errors resulting in a lack of knowledge of the scene location (does not effect image quality)**

Naval Prototype Optical Interferometer

MultiAp

Perform full scale demonstrations at a ground field site (NPOI) which has similar hardware configuration and function as MultiAp

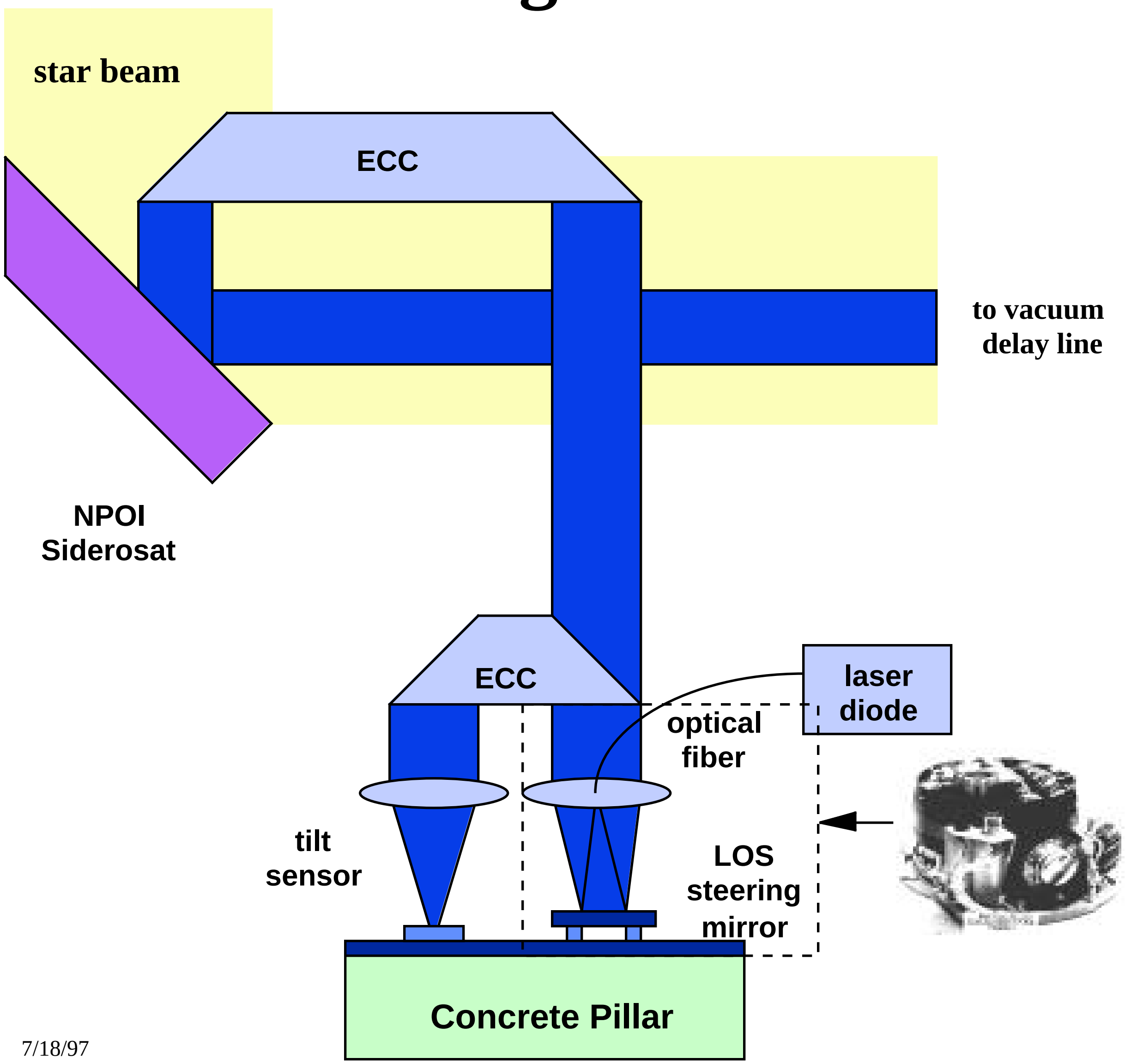
MultiAp Alignment Beam SourceAssembly

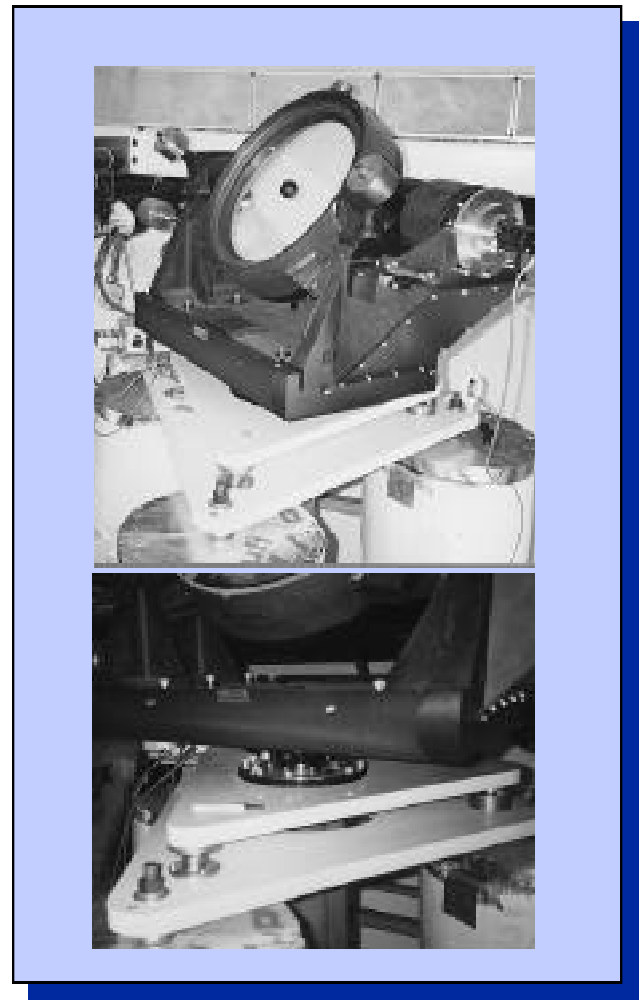


IPSRU

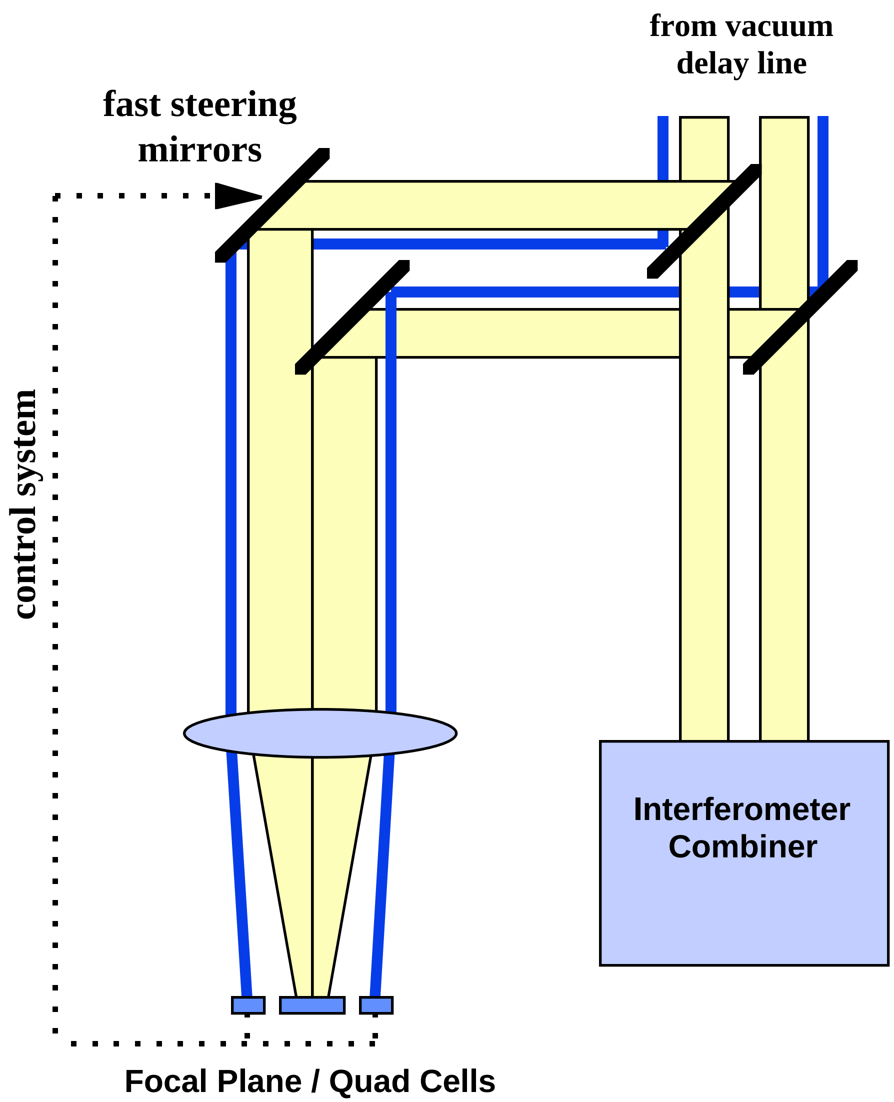
- built by Draper Labs for AF
- 40 nrads stability

NPOI Alignment Beam Source Assembly





NPOI Tilt Sensor Assembly



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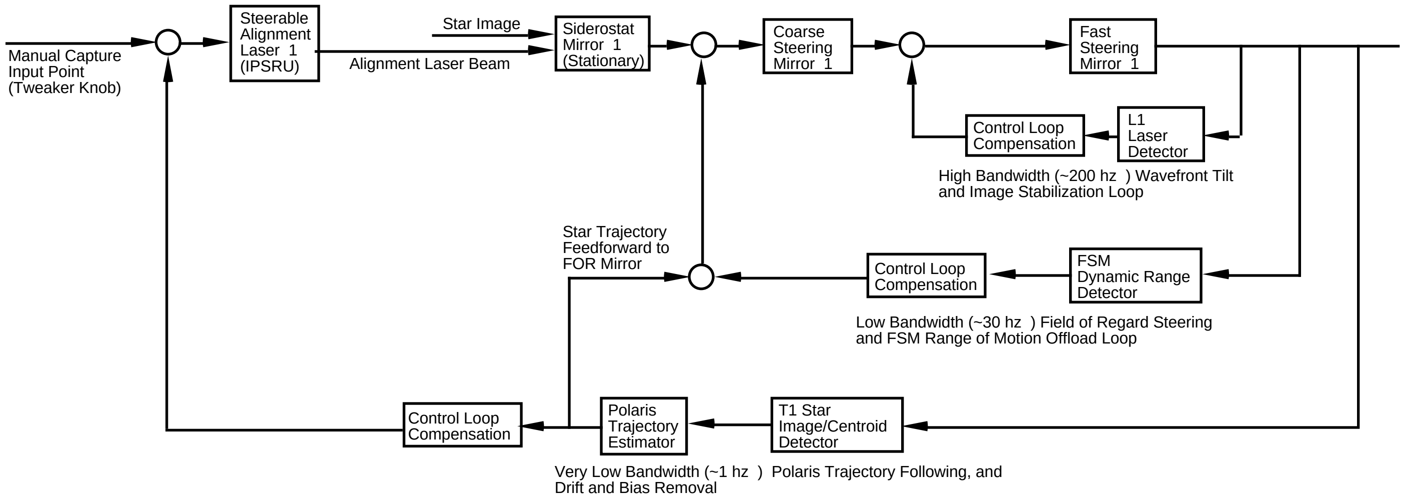
NPOI and MultiAp tilt control system

SINGLE TELESCOPE CONTROL SYSTEM BLOCK DIAGRAM



Fast Steering Mirror (FSM) Design

- **Flexure mounted mirror, reactionless design**
  - **Very good dynamic range of up to 2 deg**
- **Voice coil type electromechanical actuators**
- **Kaman proximity sensors for base reference (pointing) control loop mode**
  - **Kaman sensors seem to be poor quality (unknown exactly which model is used)**
- **Quad cell sensors and Lockheed built sensor electronics used for optical (tracking) control loop mode**
  - **These sensors and electronics are good to about 20 kHz**
- **Calibration performed with a Kern theodolite**
  - **Optical loop scale factor was very dependent on red beam spot size and quality**
  - **Scale factors also dependent on electronics gain (used to adjust loop bandwidth)**
- **Continued on next chart**

Fast Steering Mirror (FSM) Design

- **Servo is type two with a lead-lag network providing a maximum of 60 deg phase margin somewhere near 300 Hz**
  - **Servo design needs work**
  - **Compensation is different for each axis of each mirror**
  - **Same compensation is used for both base reference and optical loop modes**
  - **Undesirable poles in Kaman sensor response at 2000 Hz limits the bandwidth of the base reference loop and therefor the optical loop**
  - **Servo has inadequate phase margin at crossover so startup transients can cause unstable oscillations**
  - **Automatic switching between base reference and optical modes works well**
  - **Servo electronics have large residual biases of up to 300 mV**
  - **Kaman sensor calibration was incorrect and rework was necessary to obtain correct calibration of approximately 1 mrad/Volt**
  - **Separate servo compensation for the optical mode would fix most of the problems. If they were my mirrors I'd fix up the servo electronics for future use.**
  - **In defense of the supplier, he did deliver two pretty good FSMs in a relatively fast time and low cost**

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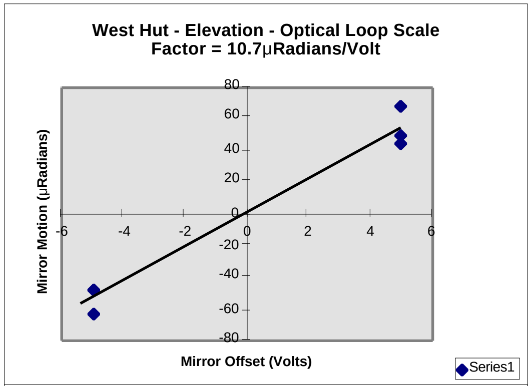
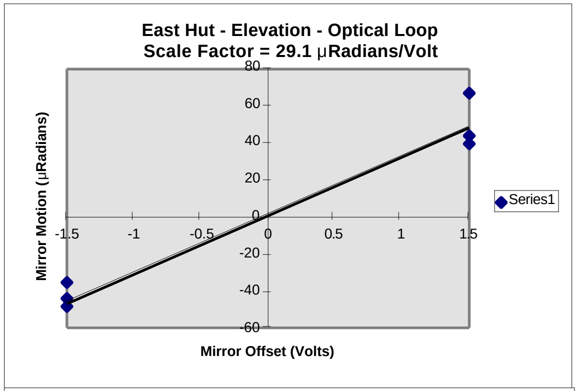
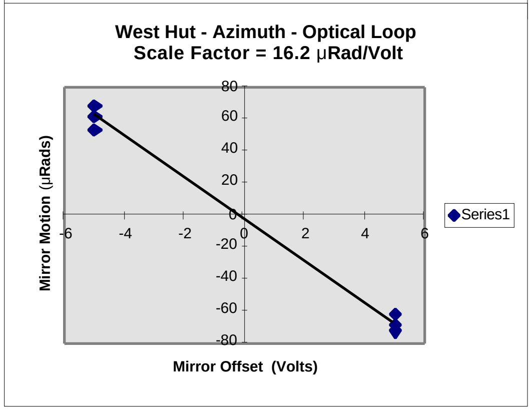
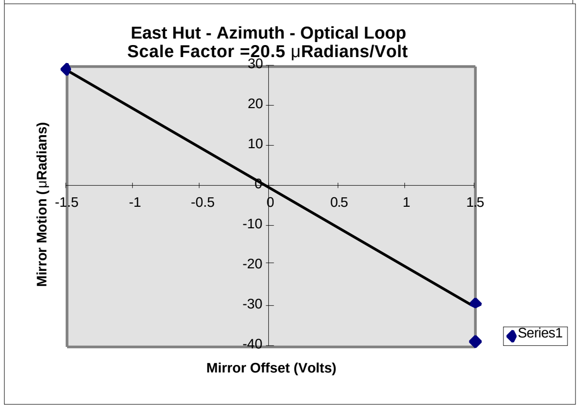
FSM Optical Mode Calibration

- **West Hut FSM** **East Hut FSM**









OTHER SCALE FACTORS OF INTEREST

- **Output space / Compact space = 1/3.57**
- **Red Beam motion / FSM Mirror motion**
  - **Azimuth: 1.4**
  - **Elevation: 2.0**
- **Green Beam Scale Factor = 2.3μrad / Volt**

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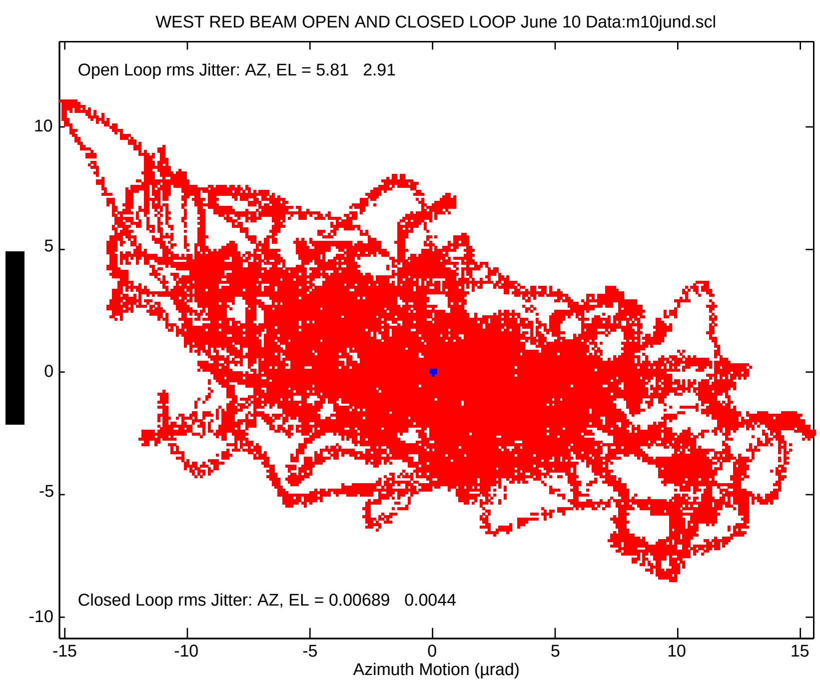
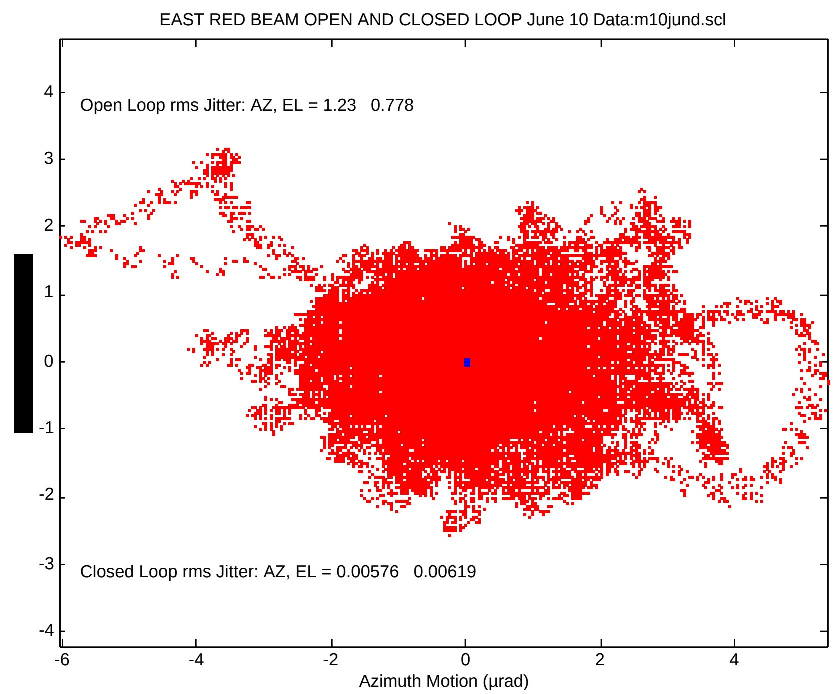
East, West Aperture LOS (red beam) Open and Closed loop (100 sec each)

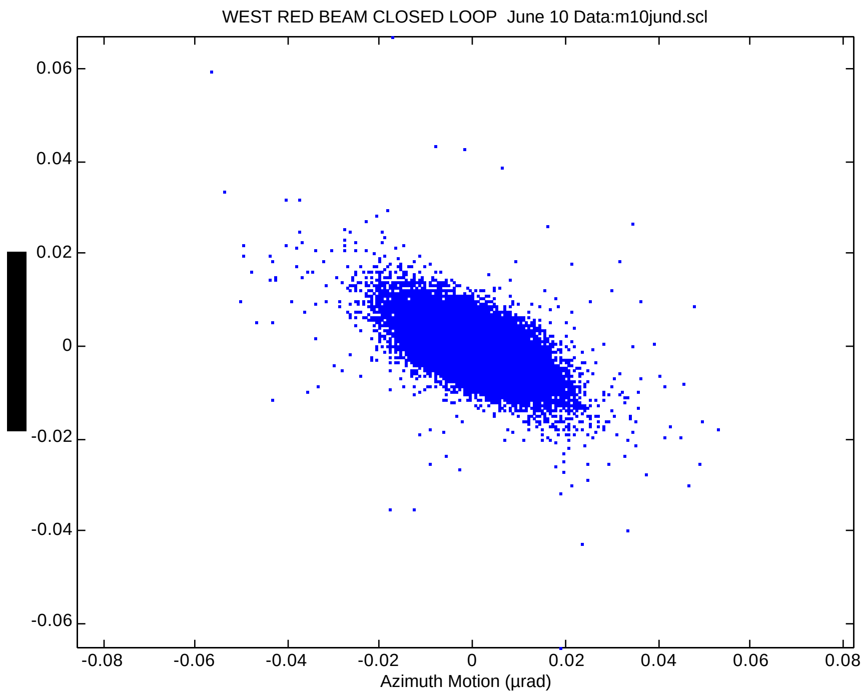
- **Red is open loop, Blue is closed loop**

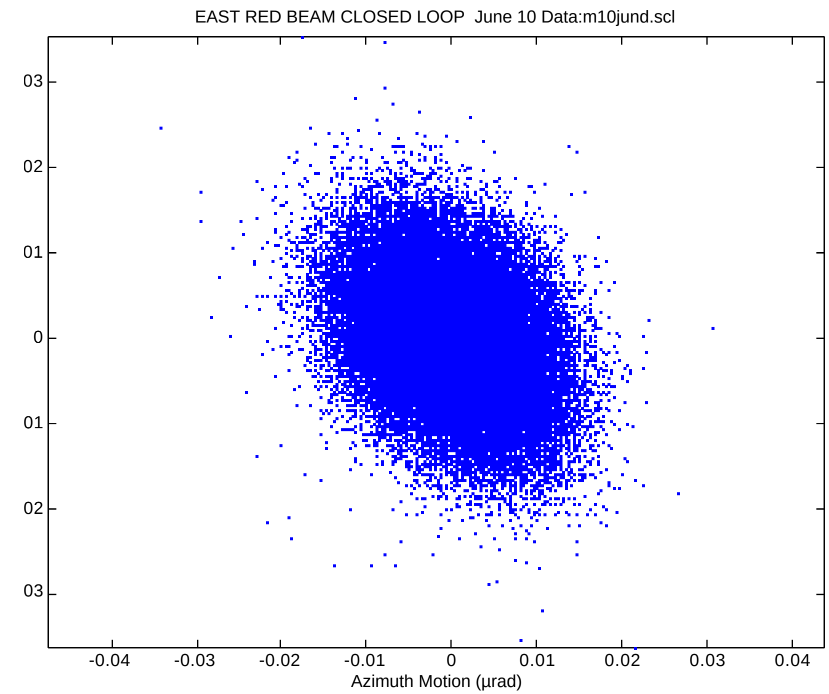


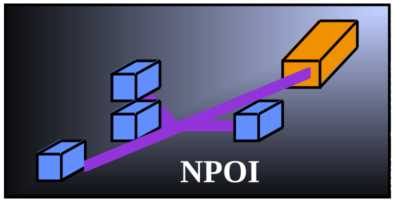


East, West Aperture LOS (red beam) Closed Loop Only (100 sec)

- **This slide shows better the residual LOS jitter time history**







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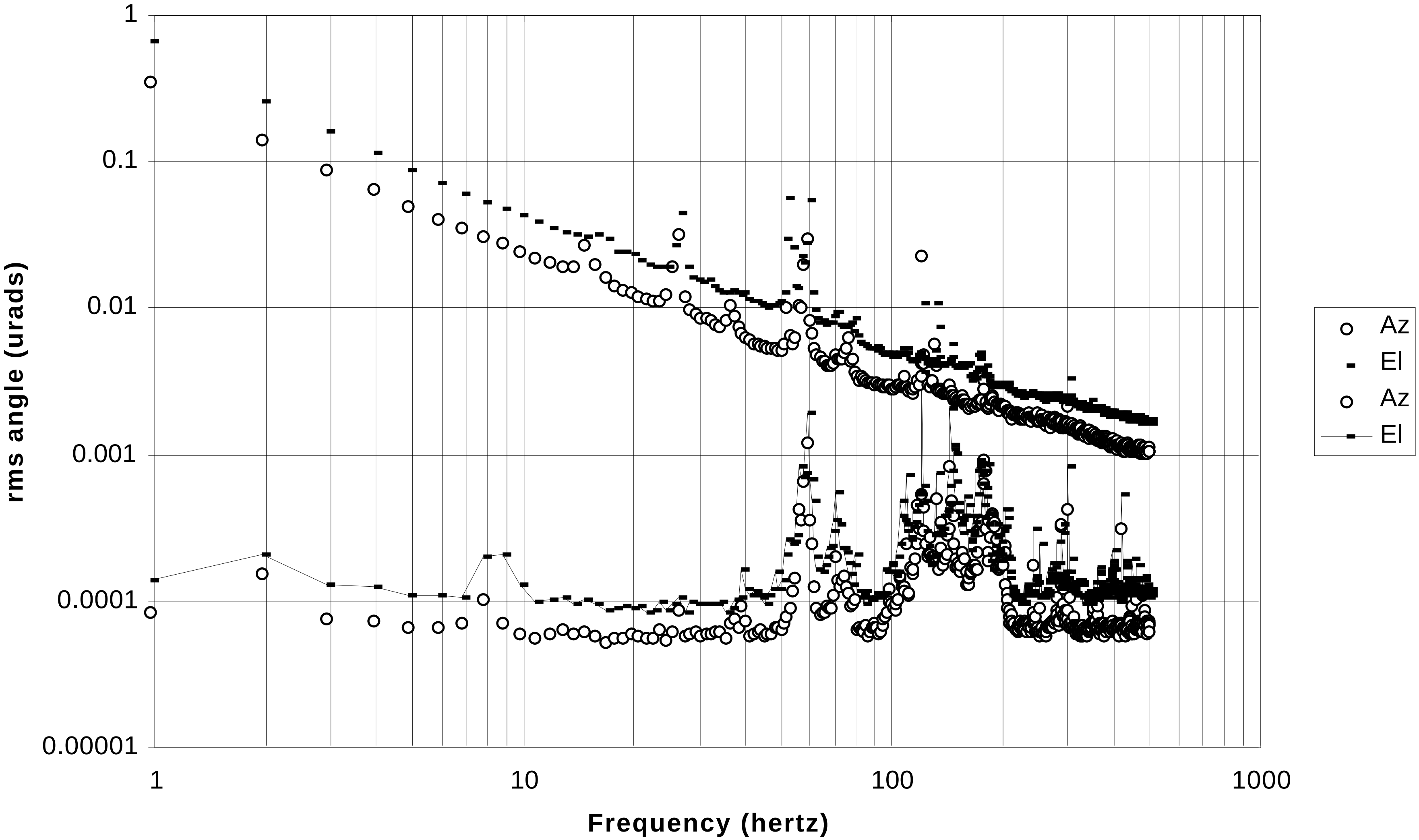
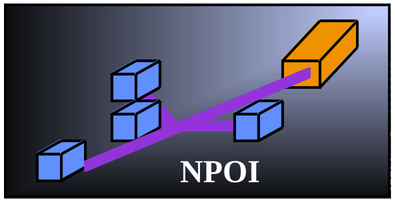
East Hut Closed Loop results





Summary

- **Demonstrated closed loop image stabilization to better than 10 nrads rms for two independent optical telescopes and delay lines**
  - **1 inch stabilized alignment beam**
  - **quad cell tilt sensor**
  - **feedback to high bandwidth FSM**
  - **100 m path length**
  - **approximately 20 reflections**
  - **few μrad rms input jitter spectrum**
- **Performance for space based system expected to be limited by the jitter on the alignment beam**
  - **IPSRU measured performance: 40 nrads rms (Draper Labs)**

Active Line of Sight Control Using Stabilized Reference Beam Demonstrated; Key Enabling Technology for Deployed NGST Concept